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Open versus endovascular revascularization for chronic mesenteric ischemia: Risk-stratified outcomes

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Objective: **Outcomes of open (OR) and endovascular revascularization (ER) for chronic mesenteric ischemia (CMI) were analyzed with respect to clinical risk stratification.**

Methods: **The data of 229 consecutive patients treated for CMI with OR (146 patients/265 vessels) or ER (83 patients/105 vessels) between 1991 and 2005 were reviewed. Patients were classified as low-risk or high-risk using standard scoring systems. End points were mortality and morbidity, recurrence-free survival, and patency rates. A subset analysis compared 111 patients (208 vessels) who had OR with 58 patients (76 vessels) who had stenting.**

Results: **The ER patients were significantly older (71 ± 15 vs 65 ± 11 years; $P < .05$), had higher risk (58% vs 31%), and fewer vessels revascularized (1.3 ± 0.5 vs 1.8 ± 0.4). Four (2.7%) procedurally related deaths occurred in the OR and two (2.4%) in the ER group (P = NS). Mortality was higher for high-risk patients (OR, 6.7% vs 0.9%; ER, 4.8% vs 0%; $P < .05$), but differences were not significant among low-risk or high-risk OR vs ER patients. OR patients had more complications (36% vs 18%; $P < .001$) and longer hospitalization (12 ± 8 vs 3 ± 5 days; $P < .001$). At 5 years, OR had improved ($P < .05$) recurrence-free survival (89% ± 4% vs 51% ± 9%), and primary (88% ± 3% vs 41% ± 9%) and secondary patency rates (97% ± 2% vs 88% ± 4%). More restenoses (hazard ratio [HR], 5.1; 95% confidence interval [CI], 2.4-10.2), recurrences (HR, 6.7; 95% CI, 3.3-13.8), and reinterventions occurred in the ER group (HR, 4.3; 95% CI, 1.9-9.7). At last follow-up, significant symptom improvement was noted in 137 OR (96%) and 72 ER patients (92%, P = NS). In the subset analysis of patients having first-time operations vs stenting, OR resulted in improved ($P < .05$) recurrence-free survival (91% ± 3% vs 56% ± 8% at 5 years) and better primary and secondary patency rates (93% ± 2% and 98% ± 1% vs 52% ± 8% and 93% ± 4% at 3 years).**

Conclusion: **OR has similar mortality but higher morbidity and longer hospitalization than ER in low-risk or high-risk patients with CMI. Both treatments effectively improved symptoms, but restenosis, recurrent symptoms, and reinterventions were more likely in ER patients. These findings may guide treatment selection and counseling of low-risk and high-risk CMI patients undergoing OR or ER procedures. (J Vasc Surg 2009;49:1472-9.)**

Chronic mesenteric ischemia (CMI) is an uncommon syndrome caused by occlusive disease of at least two of the three mesenteric arteries. Treatment goals are relief of pain, restoration of normal weight, and prevention of bowel infarction. Open revascularization (OR) has been the time-honored treatment and provides immediate relief of symptoms in most patients.[1-10] Sustained symptom improvement is noted in 78% to 100% of patients, and 3-year patency rates are 76% to 100%.[1-10] Potential disadvantages are the mortality (4% to 15%) and morbidity (20% to 30%) associated with OR.[1-10]

Endovascular revascularization (ER) has emerged as an alternative treatment in the elderly or higher-risk patient, but its use in low-risk operative candidates is not well defined.[11] Mortality rates range from 0% to 11%, symptom relief occurs in 52% to 80% of patients, and 3-year patency rates are 40% to 88%.[11-24] Direct comparison between OR and ER is difficult because of inherent differences in patient characteristics. Choice of therapy is often based on perceived clinical risk and surgeon preference.

The purpose of this study was to analyze the risk-stratified outcomes in patients treated for CMI with OR or ER. As a secondary aim, the outcomes of OR and stenting were compared after excluding patients with prior mesenteric interventions, concomitant aortic reconstructions, or angioplasty alone.

METHODS

The study was approved by the Institutional Review Board of the Mayo Clinic. We identified all consecutive patients treated for CMI between June 1, 1991, and June 1, 2005. Patients had typical symptoms of CMI caused by occlusive atherosclerotic disease treated with OR or ER. We excluded patients with acute mesenteric ischemia, non-atherosclerotic causes, and those who had prophylactic mesenteric reconstruction.

Demographics, clinical characteristics, radiologic and operative data were obtained from the medical records. Operative risk was assessed using Society for Vascular Surgery (SVS) scores. Patients were classified into a low-risk or high-risk category by the presence of at least one high-risk criterion defined in Table I (online only). Several of these

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Competition of interest: none.

Presented at the 2006 Vascular Annual Meeting, Society for Vascular Surgery, Philadelphia, Pa, Jun 1-4, 2006.

Additional material for this article may be found online at www.jvascsurg.org.

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0741-5214/$36.00

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doi:10.1016/j.jvs.2009.02.006

criteria have been validated as predictors for morbidity and mortality after open aortic reconstructions.[9,25] Early and late morbidity and mortality were recorded.

Patency was evaluated using duplex ultrasound (DUS), computed tomography (CTA) or magnetic resonance angiography (MRA), and biplane mesenteric angiography. Mesenteric run-off vessels were not systematically analyzed, but revascularization was indicated in the presence of a suitable target artery with patent runoff. Technical success was defined as a residual stenosis <30% by angiography. Follow-up consisted of clinical examination and DUS every 6 months during the first year and annually thereafter. Patients with restenoses documented by DUS underwent CTA or conventional angiography, or both.

Statistical analysis. Data were analyzed using SVS reporting standards.[26] End points were mortality, morbidity, symptom improvement, survival, patency rates, and freedom from recurrent symptoms and reinterventions. Survival and patency data were analyzed using Kaplan-Meier estimates, and differences were determined by the log-rank test. The multivariate Cox proportional hazard model was used to identify independent predictors of mortality, restenoses, and symptom recurrence requiring reintervention. The Pearson χ^2 or Fisher exact test was used for analysis of categoric variables. Differences between means were tested with two-sided *t* test, the Wilcoxon rank sum test, or the Mann-Whitney test. A value of $P < .05$ was used to determine statistical significance.

RESULTS

Patient population. There were 229 patients (64 men; 165 women) who were mean age of 67 ± 13 years. Treatment was OR in 146 patients (265 vessels) and ER in 83 (105 vessels). Clinical presentation was similar in both groups (Table II, online only), except for longer duration of symptoms in OR patients (9.7 ± 8.1 vs 6.5 ± 8 months; $P < .008$).

Clinical risk assessment. The ER group had more high-risk patients (58% vs 31%; $P < .001$). Significant differences ($P < .05$) in the ER group, summarized in Table III (online only), included older age, more men, higher SVS scores, and more coronary, pulmonary, and renal disease. Clinical variables were similar for low-risk patients in both groups. High-risk ER patients, however, were older (80 ± 7 vs 71 ± 11 years) and had more coronary artery disease (88% vs 69%), heart failure (42% vs 22%), and renal insufficiency (46% vs 22%) compared with high-risk OR patients ($P < .05$).

Angiographic features. The extent of mesenteric disease was similar between groups (Table IV, online only). Overall, 131 patients (57%) had three-vessel disease, 93 (41%) had two-vessel, and 5 (2%) had isolated superior mesenteric artery (SMA) disease. OR patients had more celiac artery (CA) and SMA occlusions (34% vs 10%; $P < .05$).

Operative treatment. OR was preferred for low-risk patients and in those with occlusions, calcified, or longer lesions. A total of 265 vessels were treated, including 143 SMA, 113 CA, and 9 inferior mesenteric arteries (IMA). Two-vessel revascularization was performed in 113 patients (77%), single-vessel in 30 (21%), and three-vessel in three (2%). Bypass was used in 136 patients (93%) and transaortic endarterectomy in 10 (7%). In 103 patients (70%), a bifurcated polyester graft was used from the supraceliac aorta to the CA and SMA. In 23 patients (16%), concomitant aortic reconstruction was needed for the mesenteric bypass. Postoperative medical therapy consisted of aspirin in 71 patients (49%) and warfarin in six (4%).

Endovascular treatment. ER was preferentially used in high-risk patients and was applied more broadly for patients with short-segment (<2-cm) stenosis. Access was obtained through the femoral artery in 72 patients (87%) and the brachial artery in 11 (13%). Of the 105 arteries (62 SMA, 38 CA, and 5 IMA) treated, balloon-expandable stents were used in 76 (72%) and angioplasty alone in 29 (28%) (Table V, online only). One vessel was revascularized in 62 patients (75%), two vessels in 20 (24%), and three vessels in 1 (1%). Fewer arteries were reconstructed in the ER group (1.3 ± 0.5 vs 1.8 ± 0.4 vessels; $P < .01$). Technical success was 95% (79 of 83), with four technical failures due to residual stenosis or dissection in two patients each. Medical therapy consisted of aspirin in 47 patients (57%), clopidogrel in 40 (48%), and warfarin in 15 (18%).

Early outcome

Symptom improvement. Symptom improvement occurred in 222 patients (97%), but symptoms were unchanged in 3 (2 OR and 1 ER) and were worse in 4 (1 OR and 3 ER). Patients treated with ER spent fewer days in the intensive care unit (ICU, 0.7 ± 3.5 vs 4.6 ± 4.8 days; $P < .0001$) and in the hospital (3 ± 5 vs 12 ± 8 days; $P < .0001$).

Procedure-related mortality. There were six (2.6%) early procedure-related deaths, four (2.7%) in the OR and two (2.4%) in the ER group (P = NS). The mortality rate for OR was 0.9% (1 of 101) in low-risk, 6.7% (3 of 45) in high-risk, and 8.6% (2 of 23) in patients who required aortic replacement. Causes of death were myocardial infarction (MI) in two patients and respiratory failure or multisystem organ failure (MOF) in one patient each. Two high-risk patients died after ER, one from MI and the other from gastrointestinal bleeding (Table VI). No differences in mortality rates were documented when we compared low-risk and high-risk patients between groups.

Effect of high-risk criteria. The 30-day mortality rate was higher for each of the high-risk criteria compared with the low-risk group, with the exception of age >80 years, stress-induced cardiac ischemia, and severe left ventricular dysfunction (Table VII). For the entire cohort, the 30-day mortality rate increased from 0.7% in low-risk patients to 3.1% with 1 criterion, 12.5% with 2 or 3, 25% with 4 or 5, and 50% with >6 high-risk criteria. Renal insufficiency and severe pulmonary dysfunction were independently associated with increased risk of early death (Table VIII).

Procedure-related morbidity. More complications occurred after OR ($P < .05$) than with ER (36% vs 18%), both in low-risk (37% vs 10%) and high-risk subgroups

Table VI. Procedurally related deaths in patients treated for chronic mesenteric ischemia with open or endovascular revascularization

Patient	*Age/sex*	*Risk assessment*	*Operation*	*Complications*	*Cause of death*	*POD*
OR						
1	75F	Low risk; Cr 1.2 mg/dL	MEA	SMA thrombosis; renal + respiratory failure; re-exploration, thrombectomy, bowel resection	MOF	52
2	75F	High risk; Cr 3.1 mg/dL; DSE–	MEA	Cardiac arrest, MI, acute on chronic renal failure	Cardiac	24
3	80F	High risk; Cr 2.7 mg/dL; 15% wt loss; severe AIOD; occluded SMA	AOFB; aortic-graft-SMA bypass	*Clostridium difficile* colitis, aspiration pneumonia, respiratory failure	Pulmonary	37
4	80F	High risk Cr 1.3 mg/dL; DSE–; FEV_1 2000 mL; 26% wt loss; juxtarenal AAA	AOIB Aortic-graft-SMA bypass	Massive MI	Cardiac	14
ER						
1	67F	High risk; Cr 2.0 mg/dL; DSE+; FEV_1 1000 mL; 39% wt loss	Celiac and SMA stent	Renal failure, no dialysis	Massive gastrointestinal bleeding (no autopsy)	3
2	69F	High risk; Cr 4.0 mg/dL; MI < 30 days; FEV_1 800 mL; 30% wt loss	SMA PTA	Cardiac arrest, MI	Cardiac	1

AOFB, Aortofemoral bypass; *AOIB,* aortoiliac bypass; *AOID,* aortoiliac occlusive disease; *Cr,* creatinine; *DSE,* dobutamine stress test (− negative or + positive); *MEA,* Mesenteric endarterectomy; *MI,* myocardial infarction; *MOF,* multisystem organ failure; *POD,* postoperative day; *PTA,* percutaneous transluminal angioplasty; *SMA,* superior mesenteric artery; *wt,* weight; *FEV_1,* forced expiratory volume in 1 second.

Table VII. Comparison of mortality rates at 30-days and 5-years in 229 patients with chronic mesenteric ischemia according to high-risk criteria defined in Table I (online only)

	30-day mortality, %			*5-year mortality, %*		
High-risk criteria	*Yes*	*No*	P[a]	*Yes*	*No*	P[a]
Age >80 y	2.7	2.6	NS	50	30	.06
Severe pulmonary dysfunction						
FEV_1 < 800 mL or DLCO <50%	17	1.4	.02	57	31	.02
Resting PCO_2 > 50 mm Hg	20	2.2	.01	34	20	NS
Resting PO_2 < 60 mm Hg	40	1.8	.001	42	33	NS
Home oxygen therapy	20	2.2	.01	43	20	.05
Severe cardiac dysfunction						
LVEF < 25%	3.5	1.5	NS	36	26	NS
NYHA III or IV angina pectoris	29	1.8	.03	62	32	.03
Positive cardiac stress test	4.8%	2.1%	NS	34	32	NS
Myocardial infarction <90 days	20	2.2	0.01	33	20	NS
Severe renal insufficiency (Cr > 3.0)	50	1.8	.01	50	33	.01
Multiple high-risk criteria						
None (low risk patient)	0.7			27		
1 criteria	3.1			31		
2 to 3 criteria	12.5			34		
4 to 5 criteria	25			47		
>6 criteria	50			69		

Cr, Creatinine; *DLCO,* diffusing capacity of lung for carbon monoxide; *LVEF,* left ventricular ejection fraction; *FEV_1,* forced expiratory volume in 1 second; *NS,* not significant; *NYHA,* New York Heart Association; *PCO_2,* partial carbon dioxide pressure; *PO_2,* partial oxygen pressure.
[a]Comparing presence (yes) or absence (no) of mortality.

(38% vs 18%), especially due to more cardiac (10% vs 2%) and pulmonary problems (15% vs 1%). The incidence of renal and gastrointestinal complications was similar in both groups (Table IX, online only).

Three ORs (2%) thrombosed, including two grafts and one SMA endarterectomy. An asymptomatic CA limb thrombosis was treated conservatively in one patient and another underwent revision of SMA limb occlusion. A third patient with thrombosis after SMA endarterectomy died of MOF despite thrombectomy and bowel resection.

Intraprocedural complications developed in eight ER patients (10%), including four dissections and four dis-

Table VIII. Multivariate analysis of independent factors associated with mortality, restenoses, and symptom recurrence in 229 patients treated for chronic mesenteric ischemia

Variable	*OR or HR*	*95% CI*	P
Early mortality			
Renal insufficiency	7.4	1.6-36	.01
Severe pulmonary dysfunction[a]	5.2	1.2-23	.02
Late mortality			
Renal insufficiency	2.4	1.2-5.0	.01
Male gender	1.8	1.0-3.4	.04
Severe cardiac dysfunction[b]	1.6	1.2-2.0	.001
Severe pulmonary dysfunction[a]	1.3	1.1-1.5	.008
Age	1.3	1.4-3.8	.05
Restenosis			
Endovascular treatment	3.8	1.8-3.9	.0008
Prior mesenteric intervention	1.5	1.0-2.2	.03
SMA diameter < 6 mm	1.4	1.3-3.4	.03
Female gender	1.3	1.2-4.7	.05
Symptom recurrence requiring reintervention			
Endovascular treatment	3.2	1.6-3.4	.0008
Diabetes	2.0	1.0-3.8	.04
Prior mesenteric intervention	1.5	1.1-2.2	.03
Female gender	1.4	1.1-2.9	.02
Age	0.98	0.96-1	.06

CI, Confidence interval; *HR*, hazard ratio; *OR*, odds ratio; *SMA*, superior mesenteric artery.

[a]Severe pulmonary dysfunction was defined as the presence of any high-risk pulmonary criteria defined in Table I (online only).

[b]Severe cardiac dysfunction was defined as the presence of any high-risk cardiac criteria defined in Table I (online only).

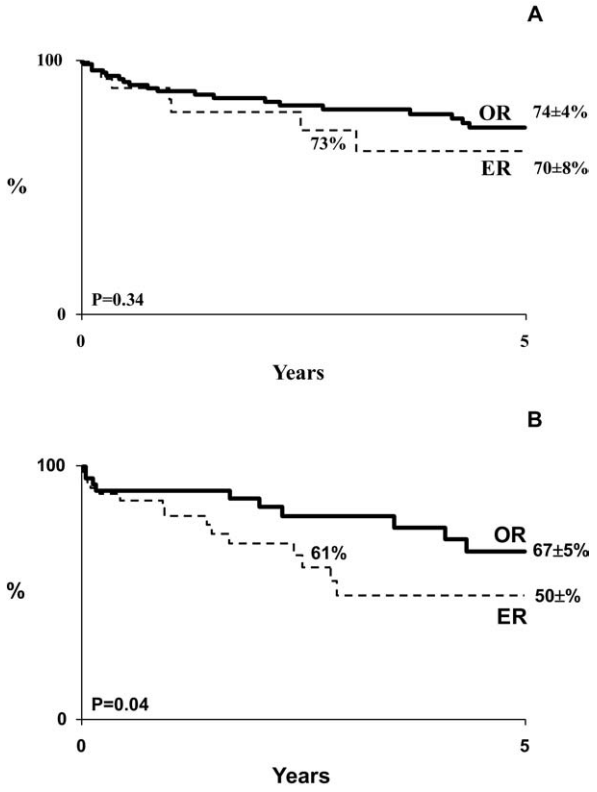

Fig 1. Kaplan-Meier estimates of patient survival in **(A)** low-risk and **(B)** high-risk patients with chronic mesenteric ischemia treated with open (*OR, solid line*) and endovascular revascularization (*ER, dashed line*).

lodged stents. These occurred using femoral access, 0.035-inch guidewire systems, and hand-mounted stents. Two of the SMA dissections occurred after multiple catheterizations through the femoral approach because of acute mesenteric angulation. Salvage procedures with additional stents were successful in five patients, but three required additional interventions for bowel ischemia. One patient needed SMA endarterectomy and patch angioplasty, another patient was successfully treated with tissue plasminogen activator and repeat stenting, and a third patient needed sigmoid resection and SMA bypass. Four patients (3%) required repair of access site complications (2 femoral and 2 brachial).

Late outcome

Median follow-up was 36 months (range, 4-179 months) in the OR group and 30 months (range, 4-174 months) in the ER group ($P < .05$). Late follow-up was available in 218 patients (98%). Objective patency studies were done in 118 OR (81%) and 51 ER patients (73%), with single studies in 31 OR (21%) and 12 ER patients (13%).

Patient survival. Overall 5-year survival was significantly higher after OR than ER (72% ± 5% vs 55 ± 9%; $P < .0001$), but was similar between low-risk patients in the OR (74% ± 4%) and ER groups (70% ± 8%; P = NS, Fig 1, *A*). Survival in the high-risk subgroups was significantly better after OR (67 ± 5% vs 50 ± 8%; $P < .04$, Fig 1, *B*). Of the high-risk criteria defined in Table I (online only), age >80 years, forced expiratory volume in 1 second (FEV_1) < 800 mL, home oxygen therapy, New York Heart Association (NYHA) functional class III and IV, and serum creatinine level >3.0 mg/dL, adversely affected survival on univariate analysis (Table VII). The multivariate model showed renal insufficiency, male gender, age, and severe cardiac or pulmonary dysfunction were independently associated with late death (Table VIII).

Restenosis, symptom recurrence, and repeat interventions. Restenoses occurred in 10 patients (12 vessels) treated with OR and in 31 patients (41 vessels) treated with ER (hazard ratio [HR], 5.1; 95% confidence interval [CI], 2.4-10.2; $P < .0001$). Multivariate analysis identified endovascular treatment, prior mesenteric intervention, small (<6-mm) SMA diameter, and female gender as independent predictors for restenosis (Table VIII).

Recurrent symptoms occurred in eight OR (6%) and 26 ER (31%) patients (HR, 6.7; 95% CI, 3.3-13.8; $P < .001$). Freedom from recurrent symptoms at 5 years was higher ($P < .001$) in OR patients vs the ER patients (89% ± 4% vs 51% ± 9%; Fig 2), both for low-risk (94% ± 4% vs 57% ± 9%) and high-risk patients (89% ± 4% vs 55% ± 9%). There

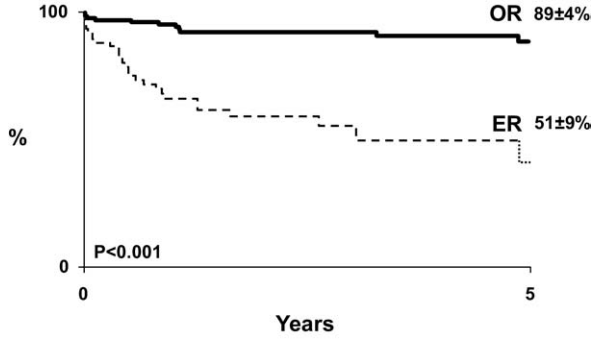

Fig 2. Kaplan-Meier estimates of survival free of recurrent symptoms in patients treated for chronic mesenteric ischemia with open (*OR, solid line*) or endovascular revascularization (*ER, dashed line*).

were no differences in freedom from recurrent symptoms at 5 years for patients who had single-vessel vs two-vessel OR (92% ± 5% and 89% ± 4%), in the 3-year rates for single-vessel vs two-vessel ER (57% ± 7% and 57% ± 12%), or in the 2-year rates for angioplasty alone vs stenting (63% ± 9% and 59% ± 8%). Endovascular treatment, diabetes, prior mesenteric intervention, and female gender were independently associated with symptom recurrence requiring repeat intervention (Table VIII).

Repeat interventions were needed in all eight OR and 26 ER patients with symptoms because of restenoses (HR, 4.3; 95% CI, 1.9-9.7; $P < .0001$). Four OR patients required emergency operations for acute thrombosis (2 revisions and 2 bypasses), and the other fours were treated with ER (3 stents and 1 angioplasty for chronic symptoms). Chronic symptoms in 23 ER patients were treated with additional angioplasty or stenting (multiple in 6), and three underwent OR to treat acute mesenteric ischemia. No deaths occurred with repeat interventions in either group, and all patients reported symptom resolution. At the last follow-up, 137 OR (96%) and 72 ER patients (92%) conferred symptom improvement (P = NS).

Patency rates. Cumulative primary and secondary patency rates at 5 years were higher for OR compared with ER (88% ± 2% and 97% ± 2% vs 41% ± 9% and 88% ± 4%; $P < .005$; Fig 3). Primary and secondary patency rates favored OR in both low-risk (94% ± 2% and 98% ± 2% vs 66% ± 11% and 79 ± 9%) and high-risk patients (90% ± 4% and 96 ± 3% vs 65% ± 9% and 95 ± 3%), and SMA grafts compared with SMA angioplasty or stent (91% ± 9% and 97% ± 2% vs 50% ± 9% and 88% ± 6%) or celiac grafts compared with celiac angioplasty or stent (93% ± 3% and 98% ± 2% vs 60% ± 3% and 91% ± 2%). In the ER group, there were no differences in patency rates for angioplasty vs stents or for SMA vs celiac stents (Fig 4, *B* online only).

Comparison of first-time stenting vs open revascularization. Treatment consisted of OR in 111 (208 vessels) and stents in 58 (76 vessels), with 93% of the latter group treated after 1999. There were more high-risk patients in the stent group (59% vs 29%). Freedom from

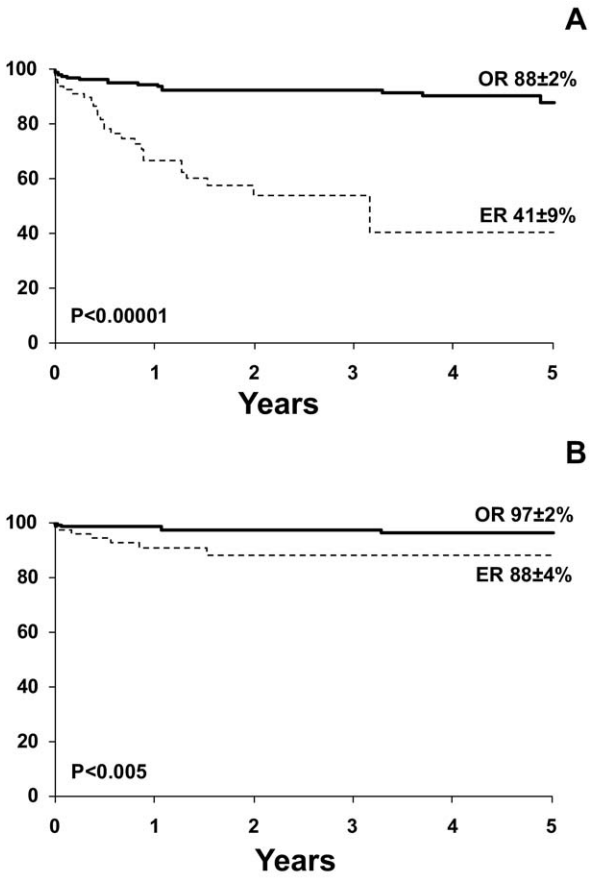

Fig 3. Kaplan-Meier estimates of **(A)** primary and **(B)** secondary patency rates in patients treated for chronic mesenteric ischemia with open (*OR, solid line*) or endovascular revascularization (*ER, dashed line*).

recurrent symptoms at 5 years was 91% ± 3% for OR and 56% ± 8% for stenting ($P < .001$). OR was associated with significantly higher primary and secondary patency rates at 3 years (93% ± 2% vs 52% ± 8% and 98% ± 1% vs 93 ± 4%; $P < .05$).

DISCUSSION

The interpretation of treatment guidelines for CMI based on the available literature is difficult for several reasons. First, results of OR (in healthier patients) and ER (in sicker patients) are not comparable. Second, some reports have small patient numbers treated over long time periods, or patients with acute and chronic presentations with a variety of etiologies such as arteritis and median arcuate ligament syndrome. Third, reporting standards are inconsistent, with no uniform definition of technical success after ER and lack of objective patency determination in several studies. To our knowledge, this study is the first to detail outcomes of mesenteric interventions by clinical risk stratification.

Open mesenteric revascularization has evolved during the last two decades and is the standard for comparison of

endovascular techniques.[1-11] Our practice has evolved from complete retrograde revascularization and a low threshold for concomitant aortic reconstruction to a preferential use of antegrade reconstructions based on the supraceliac aorta, reserving aortic reconstruction for the rare patient who needs it for an inflow source or in whom aortic pathology necessitates repair.[1] We have found the iliac artery to be good source of inflow in high-risk patients or those with diseased or calcified aortas.

A "high" mortality rate is often cited as the primary reason for ER in patients with CMI. Contemporary series of open mesenteric revascularizations have shown improvements in mortality rates, likely due to technical refinements and advances in medical, anesthetic, and critical care management.[1,6-7] Our overall mortality rate of 2.7% in the OR group shows these reconstructions can be performed safely. Importantly, our best (low-risk) operative candidates, 70% of whom had supraceliac-based reconstructions, had a low mortality rate of 0.9%. The overall mortality rates were similar between the OR and ER groups, and there were no significant differences in mortality when low-risk and high-risk patients were analyzed separately for OR vs ER procedures. High-risk patients, as defined by our criteria, obviously impart a higher operative mortality (6.7%), and the same is true for those who require concomitant aortic reconstruction (8.9%).

Differences in mortality and outcomes between OR and ER may be due to lack of risk stratification. The effect of high-risk criteria, as defined in this study, provides some useful clinical guidelines. The 30-day mortality rate significantly increased in any patient with severe pulmonary dysfunction, NYHA class III or IV angina pectoris, recent MI, or severe renal insufficiency. The 5-year mortality rate was significantly higher in patients with low FEV_1, low diffusing lung capacity, home oxygen, NYHA class III or IV angina pectoris, or severe renal insufficiency. Furthermore, the more high-risk criteria a given patient had, the higher the 30-day and 5-year mortality rates. A low-risk patient, defined as having no high-risk criteria, had an overall mortality rate of 0.7% at 30 days and 27% at 5 years. With one high-risk criterion, the mortality rates increased to 3.1% at 30 days and 31% at 5 years. If four or more high-risk criteria were present, the mortality rate at 30 days was at least 25%, and more than two-thirds of patients were dead ≤5 years. All but one of the six procedurally related deaths in occurred in high-risk patients. Among these five, the number of high-risk criteria ranged from two to four, and the predicted 30-day mortality rate would have been 12.5% to 25%.

Initial symptom improvement is excellent with either approach. The main advantage of ER is a lower risk of complications, most notably cardiac and pulmonary problems. The incidence of complications is nearly half that of OR. Similar to other reports comparing the two techniques, endovascular interventions result in shorter ICU and hospital stays, which may translate into a quicker patient recovery and less cost during the initial hospitalization.[16,21]

OR is clearly durable. In this study, freedom from recurrent symptoms was 89% at 5 years and primary patency was 88%. The superior durability of open mesenteric reconstruction over endovascular therapy has been confirmed in other series.[16,21] Moreover, patients treated with ER in this study were five times more likely to develop restenosis, seven times more likely to have recurrent symptoms, and four times more likely to undergo another intervention. Independent predictors for symptom recurrence included ER, diabetes, prior mesenteric intervention, and female gender.

Nonetheless, several centers prefer ER for all patients with suitable lesions, regardless of their clinical risk. The enthusiasm for endovascular techniques may be due to a number of factors, including the limited exposure or training a vascular surgeon has in performing open mesenteric reconstructions and the high mortality rates (8% to 15%) of OR in some reports.[1,2,7] Our study certainly refutes the latter argument. However, angioplasty or stenting carries lower morbidity, faster recovery time, and excellent initial symptom improvement, albeit at the expense of more symptomatic restenoses and repeat interventions. Despite the need for repeat interventions in almost one-third of the patients in our study, 92% had symptom relief at last follow-up. Brown et al[21] noted 57% of their patients required repeat intervention, but 93% reported symptom improvement during follow-up.[21] Therefore, if endovascular therapy is chosen, patients need to be counseled about the advantages and disadvantages of the technique, and close follow-up with arterial imaging becomes paramount.

We noted more dissections and dislodged stents early in our experience when the femoral approach was preferentially used, stents were hand mounted, and delivery systems were introduced over 0.035-inch wires. Sarac et al[23] reported higher mortality rates in patients who had mesenteric interventions by the femoral approach. It is possible that the femoral approach leads to more catheter manipulation and risk of complications. We now prefer the brachial artery access in patients with angulated mesenteric origin, and with the technologic improvements in the delivery system, the risk of complications has fallen.

Whereas most agree the SMA should be the primary target for revascularization, no differences were noted in freedom from recurrent symptoms for single-vessel vs two-vessel OR or ER. Our preference for OR is to reconstruct two vessels, because we previously reported that symptomatic recurrence after OR occurred when both limbs of a bifurcated graft failed or when a single graft to the SMA became stenotic.[9] Stenosis of one limb of a bifurcated graft has not resulted in recurrent symptoms. In contrast, we have not adopted the same policy as others toward two-vessel ER. Silva et al[22] reported more symptomatic recurrences in patients who had single-vessel (24%) vs two-vessel (6%) stenting, but the difference was not significant ($P <$ .09). In our study, the initial advantage in symptom-free survival at 2 years in patients who had two-vessel interventions (73 ± 10% vs 57% ± 7%) was lost by 3 years. Therefore, we stent the SMA first, and selectively treat the

CA in patients who have flow-limiting residual SMA stenosis or dissection after treatment. Our study has several limitations. Because the data were analyzed retrospectively and the study was nonrandomized, we cannot comment about the exact circumstances that affected the choice of therapy. Second, despite our risk-stratified analysis, some of the clinical differences favored the OR group. This group had more vessels treated and the high-risk patients were younger and had less coronary and renal disease than the high-risk patients in the ER group. These factors could explain differences in late survival between groups. Third, endovascular technology has evolved rapidly, and some of our results would not reflect the effect of the small-profile systems on outcome. Finally, although 81% of the OR group and 73% of the ER group had at least one imaging study, restenoses rates may be underestimated.

CONCLUSIONS

Experienced surgeons can safely perform OR for CMI, and mortality rates compare favorably with endovascular treatment, albeit at the expense of more complications and longer hospitalization. Symptom relief is excellent with both treatment modalities, but endovascular therapy is associated with higher rates of restenosis and symptom recurrence. Our approach to these patients continues to evolve. Anatomically low-risk patients with long segment occlusions or stenosis, heavily calcified lesions, or atheromatous debris may be better suited for OR. ER is preferred for high-risk patients and may be an alternative to OR in low-risk patients with ideally suited lesions. Whether the preferential use of ER in the low-risk patient becomes standard of practice is yet to be determined, but certainly such individuals should be counseled about the higher rates of repeat interventions with mesenteric stenting.

We gratefully acknowledge the assistance of Joseph Miskulin, BS, Rafael Malgor, MD, and Janet Hofer, RN with data collection and management, and Carl Clingmann with preparation of medical illustrations.

AUTHOR CONTRIBUTIONS

Conception and design: GO, TB, TS
Analysis and interpretation: GO, TB, TS, SC
Data collection: GO
Writing the article: GO, TB, TS
Critical revision of the article: GO, TB, TS, HB, SC, PG
Final approval of the article: GO, TB, TS, HB, SC, PG
Statistical analysis: GO, TB, TS, SC
Obtained funding: GO
Overall responsibility: GO

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Submitted Feb 6, 2007; accepted Feb 3, 2009.

Additional material for this article may be found online at www.jvascsurg.org.

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Table I (online only). Definitions of high-risk criteria for mesenteric artery intervention

Age >80 years
Severe pulmonary dysfunction
FEV_1 <800 mL or DLCO <50% of predicted
Resting P_{CO_2} >50 mm Hg or P_{O_2} <60 mm Hg
Home oxygen therapy
Severe cardiac dysfunction
Left ventricular ejection fraction <25%
NYHA class III or IV angina pectoris
Cardiac stress test positive for myocardial ischemia
Myocardial infarction ≤90 days
Severe renal insufficiency (baseline Cr >3.0 mg/dL)

Cr, Creatinine; *DLCO,* diffusing capacity of the lung for carbon monoxide; *FEV_1,* forced expiratory volume in 1 second; *NYHA,* New York Heart Association; *P_{CO_2},* partial pressure of carbon dioxide; *P_{O_2},* partial pressure of oxygen.

Table II (online only). Clinical presentation in 229 patients with chronic mesenteric ischemia treated with open (OR) or endovascular (ER) mesenteric artery revascularization

	OR (n = 146)	*ER (n = 83)*	
Signs and symptoms	*Mean ± SD or No. (%)*	*Mean ± SD or No. (%)*	P
Symptom duration, mon	9.7 ± 8.1	6.5 ± 8	.008
Abdominal pain	137 (94)	82 (99)	NS
Weight loss	128 (88)	65 (78)	NS
Baseline weight, kg	67.3 ± 15	69.6 ± 12.3	NS
Weight at presentation, kg	57.7 ± 16	60.3 ± 13.0	NS
Absolute weight loss, kg	9.7 ± 6.8	9.3 ± 7.7	NS
Weight loss, %	14.9 ± 10	13.5 ± 10.7	NS
Postprandial pain	109 (75)	60 (72)	NS
Abdominal bruit	70 (48)	30 (37)	NS
Food fear	68 (47)	36 (43)	NS
Diarrhea	61 (42)	30 (36)	NS
Nausea and vomiting	48 (33)	18 (22)	NS
Prior mesenteric intervention	12 (8)	6 (7)	NS
Prior small-bowel resection	9 (6)	6 (7)	NS
Total parenteral nutrition	3 (2)	3 (4)	NS
Gastrointestinal bleeding	1 (1)	2 (2)	NS

ER, Endovascular revascularization; *NS,* not significant; *OR,* open revascularization; *SD,* standard deviation.

Table III (online only). Demographics, cardiovascular risk factors, and perioperative risk assessment in 229 patients with chronic mesenteric ischemia treated with open or endovascular mesenteric artery revascularization

	OR (n = 146)	*ER (n = 83)*	
Demographics	*Mean ± SD or No. (%)*	*Mean ± SD or No. (%)*	P
Male gender	34 (23)	30 (36)	.03
Age y	65 ± 11	71 ± 15	<.001
Age >80 y, No. (%)	9 (6)	30 (36)	<.0001
Cardiovascular risk factors			
Smoking	118 (81)	55 (66)	.01
Hypertension	108 (74)	69 (83)	NS
Hyperlipidemia	70 (48)	50 (60)	NS
Coronary artery disease	54 (37)	55 (66)	<.001
Positive cardiac stress test	25 (17)	17 (20)	NS
Myocardial infarction <90 d	2 (1)	8 (10)	<.006
NYHA class III or IV angina	0 (0)	7 (8)	<.001
Heart valve disease	24 (17)	24 (29)	.02
Arrhythmia	21 (14)	23 (28)	.01
Congestive heart failure	11 (8)	21 (25)	<.001
Ejection fraction <25%	8 (5)	24 (28)	<.001
Peripheral arterial disease	51 (35)	32 (39)	NS
Chronic pulmonary disease	31 (21)	29 (35)	.02
FEV_1 <800 mL	9 (6)	13 (15)	.03
P_{O_2} <60 or P_{CO_2} >50 mm Hg	9 (6)	18 (22)	<.001
Home oxygen therapy	0 (0)	5 (6)	.002
Renal insufficiency (Cr >1.5 mg/dL)	24 (16)	25 (30)	.01
Severe (Cr >3.0 mg/dL)	5 (3)	5 (6)	NS
Dialysis-dependent	1 (1)	1 (1)	NS
Diabetes	20 (14)	19 (23)	NS
Cerebrovascular disease[a]	18 (12)	36 (43)	<.0001
Perioperative risk assessment			
Any high-risk criteria[b]	45 (31)	48 (58)	<.001
SVS score			
Cardiac	0.7 ± 0.9	1.3 ± 1.2	<.001
Pulmonary	0.4 ± 0.8	0.6 ± 1.1	.05
Renal	0.2 ± 0.5	0.3 ± 0.6	NS
Sum score	1.3 ± 1.5	2.3 ± 1.4	<.001

Cr, Creatine; *ER,* endovascular revascularization; *FEV_1,* forced expiratory volume in 1 second; *NS,* not significant; *NYHA,* New York Heart Association; *OR,* open revascularization; *SD,* standard deviation; *SVS,* Society for Vascular Surgery; *P_{CO_2},* partial pressure of carbon dioxide; *P_{O_2},* partial pressure of oxygen; *SVS,* Society for Vascular Surgery.

[a]History of transient ischemic attack/stroke, presence of >50% carotid artery stenosis, or both.

[b]See Table I, online only.

Table IV (online only). Angiographic features and extent of disease in 229 patients with chronic mesenteric ischemia treated with open (OR) or endovascular (ER) mesenteric artery revascularization[a]

Variable	*OR (n = 146) No. (%)*	*ER (n = 83) No. (%)*
Single-vessel disease	3 (2)	2 (3)
Two-vessel disease	63 (43)	30 (36)
Three-vessel disease	80 (55)	51 (61)
Celiac axis		
Normal	10 (7)	5 (6)
Stenosis <40%	5 (3)	5 (6)
Stenosis 40%-69%	6 (4)	4 (5)
Stenosis >70%	87 (60)	59 (71)
Occlusion[b]	38 (26)	10 (12)
Superior mesenteric artery		
Normal	1 (1)	4 (5)
Stenosis <40%	4 (3)	6 (7)
Stenosis 40%-69%	3 (2)	4 (5)
Stenosis >70%	78 (53)	62 (75)
Occlusion[b]	60 (41)	7 (8)
Inferior mesenteric artery		
Normal	16 (11)	7 (8)
Stenosis <40%	13 (9)	10 (12)
Stenosis 40%-69%	9 (6)	0 (0)
Stenosis >70%	57 (39)	28 (34)
Occlusion[b]	37 (25)	38 (46)
Not evaluated	14 (10)	0 (0)
Abdominal aorta		
Normal	74 (52)	41 (49)
Aneurysmal disease[b]	26 (18)	9 (11)
Occlusive disease[b]	43 (30)	33 (40)

ER, endovascular revascularization; *OR*, open revascularization.
[a]For analysis of number of diseased vessels we included only arteries with stenosis >70% or occlusions. The degree of stenosis was established based on review of reports of mesenteric angiographies obtained using anteroposterior and lateral views or review. Mesenteric runoff data were not systematically reviewed.
[b]$P < .05$.

Table V (online only). Technical details of endovascular interventions in 105 mesenteric arteries in 83 patients with chronic mesenteric ischemia

Detail	*No. (%) or Mean ± SD*
Total patients	83
Single-vessel	62 (75)
Two-vessels	20 (24)
Three-vessels	1 (1)
Total arteries	105
Angioplasty and stenting	76 (72)
Celiac axis	29 (27)
Superior mesenteric artery	45 (43)
Inferior mesenteric artery	2 (2)
Stent diameter	6.1 ± 0.8
5 mm	11 (14)
6 mm	31 (41)
7 mm	28 (37)
8-10 mm	6 (8)
Total stented length	17.3 ± 5.1
12-15 mm	29 (38)
15-20 mm	35 (46)
20-30 mm	9 (12)
30-40 mm	3 (4)
Angioplasty only	29 (28)
Celiac axis	9 (9)
Superior mesenteric artery	17 (16)
Inferior mesenteric artery	3 (3)
Balloon diameter	5.9 ± 0.1
5 mm	5 (5)
6 mm	16 (15)
7 mm	8 (8)

SD, Standard deviation.

Table IX (online only). Early periprocedural complications in 229 patients treated for chronic mesenteric ischemia with either open or endovascular revascularization.

Complications	*OR (n = 146), No. (%)*	*ER (n = 83), No. (%)*	P
Any complication	53 (36)	15 (18)	.003
Cardiac complications	14 (10)	2 (2)	.04
Myocardial infarction	6 (4)	2 (2)	NS
Arrhythmia	8 (5)	0 (0)	.05
Congestive heart failure	2 (1)	0 (0)	NS
Pulmonary complications	22 (15)	1 (1)	.0008
Pneumonia	8 (5)	0 (0)	.05
Pneumothorax	2 (1)	0 (0)	NS
Respiratory failure	8 (5)	1 (1)	.05
Prolonged MV/tracheostomy	6 (4)	0 (0)	NS
Renal complications	5 (3)	7 (8)	NS
Acute renal failure	5 (3)	7 (8)	NS
Dialysis	0 (0)	0 (0)	NS
TIA/stroke	0 (0)	0 (0)	NS
Gastrointestinal complications	20 (14)	5 (6)	NS
Prolonged ileus	12 (8)	0 (0)	.05
Gastrointestinal bleeding	2 (1)	2 (2)	NS
Pancreatitis	2 (2)	0 (0)	NS
Ascites/compartment syndrome	1 (0.5)	0 (0)	NS
Ischemic colitis	1 (0.5)	2 (2)	NS
HIT/pulmonary embolism	3 (2)	0 (0)	NS
Surgical complications	9 (6)	7 (8)	NS
Mesenteric artery/graft thrombosis	3 (2)	3 (4)	NS
Wound infection/dehiscence	4 (3)	NA	...
Major bleeding[a]	3 (2)	0 (0)	NS
Bowel infarction	1 (0.5)	3 (4)	NS
Puncture site complications	NA	4 (4)	...
Pseudoaneurysm	NA	2 (2)	...
Distal thrombosis/ embolization	NA	2 (2)	...
Early reintervention	7 (5)	5 (6)	NS
Wound débridement	2 (1)	0 (0)	NS
Exploration for bleeding	3 (2)	0 (0)	NS
Bowel resection	1 (0.5)	3 (4)	NS
Mesenteric thrombectomy/ revision	2 (1)	2 (2)	NS
Mesenteric lytic therapy	0 (0)	1 (1)	NS
Repair pseudoaneurysm	0 (0)	2 (2)	NS
Extremity thrombectomy	0 (0)	2 (2)	NS

ER, endovascular revascularization; *HIT,* Heparin-induced thrombocytopenia; *MV,* mechanical ventilation; *NA,* not applicable; *NS,* not significant; *OR,* open revascularization; *TIA,* transient ischemic attack.
[a]Major bleeding requiring exploration.

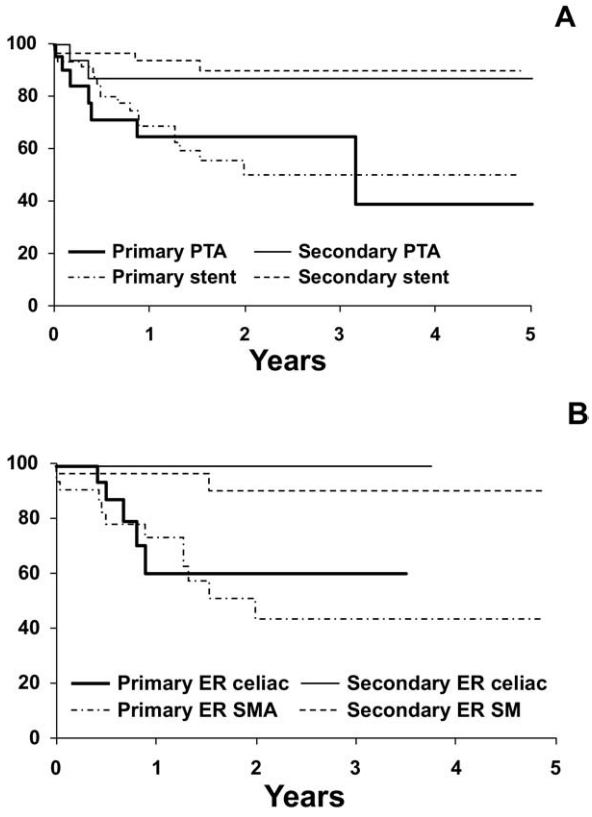

Fig 4 (online only). A, Kaplan-Meier estimates of primary and secondary patency rates in patients treated for chronic mesenteric ischemia treated with percutaneous transluminal angioplasty (*PTA*) or stent placement. **B,** Patency rates are shown for percutaneous celiac and superior mesenteric artery (*SMA*) interventions.